US Army Corps
of Engineers
Hydrologic Engineering Center

Application of Spatial Data Management Techniques to HEC-1 Rainfall-Runoff Studies

October 1983

TD-19

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1983	Training Document No. 19

4. TITLE AND SUBTITLE
Application of Spatial Data Management Techniques to HEC-1 Rainfall-Runoff Studies

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
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8. PERFORMING ORGANIZATION REPORT NUMBER
TD-19

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release. Distribution of this document is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document described a procedure for application of spatial data management techniques to HEC-1 rainfall-runoff studies. The procedure is intended to assist hydrologic engineers interested in making use of a grid cell data bank in their studies. The necessary steps to complete a hydrologic engineering rainfall-runoff study of a given watershed for either hypothetical or historical storm events are presented. The user will be required to understand the input instruction for portions of the BANK and

RIA programs and the hydrologic analysis programs HYDPAR and HEC-1.

14. SUBJECT TERMS
spatial data management, grid cell data banks, rainfall-runoff modeling, hydrologic engineering, analytical techniques, training

15. NUMBER OF PAGES
74

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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PREFACE

This training document describes a procedure for application of spatial data management techniques to HEC-1 rainfall-runoff studies. The procedure is intended to assist hydrologic engineers interested in making use of a grid cell data bank in their studies. The necessary steps to complete a hydrologic engineering rainfall-runoff study of a given watershed for either hypothetical or historical storm events are presented. The user will be required to understand the input instructions for portions of the BANK and RIA programs and the hydrologic analysis programs HYDPAR and HEC-1. This document does not provide detailed background regarding why each step needs to be accomplished in the way described. References mentioned in the text are available that provide such detail.

The document was prepared by Brian W. Smith, hydraulic engineer, under the supervision of Darryl W. Davis, Chief, Planning Analysis Branch. R. G. Willey, hydraulic engineer, developed the spatial data bank and executed the analysis programs. Bill S. Eichert was Director of the Hydrologic Engineering Center during the preparation of the document.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION AND OVERVIEW

The basic elements of a rainfall-runoff hydrologic engineering study are an analysis to determine rainfall excess, that which contributes to runoff, and a means for converting rainfall excess to streamflow--for storm events and stream locations that are of interest. Historically, hydrologic engineers carefully studied recorded major storm events to develop insight into the nature of the storm, rainfall excess relationships, and the relationship needed to convert rainfall excess to streamflow. Given the insights gained, historical or synthetic events, such as the standard project storm, were developed and their streamflow calculated. Basic data development, map data extractions, and computations were performed mostly by hand.

A wide variety of rainfall-runoff computer models designed to perform essentially the same task, determine rainfall excess and translate the result to runoff hydrographs, is now available. Study of historic events is still required in order to gain the necessary insights and derive loss rate and runoff transform functions. Map work is required to delineate subbasins; determine drainage areas; and develop spatial distributions of precipitation, losses, and runoff. The resulting basin characteristics are used to develop coefficients needed to perform computer model calculations. Much of the data used in a typical rainfall-runoff modeling effort is spatial, i.e., has locational attributes, such as terrain, soil types, drainage areas and land cover. The spatial data are most often obtained from a map. Map data can now be computerized and made available for use in technical studies such as rainfall-runoff modeling.

"Spatial data management" technology is available and operational for use with modern rainfall-runoff models. The hydrologic engineer may create a spatial data bank of the relevant map data for a rainfall-runoff study and automatically link the spatial data through analysis programs to the HEC-1 program (Hydrologic Engineering Center 1981a). In effect, much of the map work, coefficient derivation, and input work needed to use HEC-1 in a rainfall-runoff study has been automated to ease the data management burden of the technical analyst. This permits efficient study of such issues as the impact of alternative future urban development, on-site water management measures, sensitivity of results to spatial variation in rainfall and model parameters, and a range of other management alternatives.

This document presents an example of the creation of a grid cell data bank containing relevant data to a HEC-1 rainfall-runoff study. The emphasis is on creating a grid cell data bank using simple concepts and readily available computer programs so that a hydrologic engineer can undertake the task and be successful without either special training or specialized equipment. The example HEC-1 application is basic but should provide adequate illustration of the procedure so the hydrologic engineer can perform more complex studies on his own.

Documentation is available on the general subject of spatial data bank creation. Background information and guidance is provided in Guide Manual for the Creation of Grid Cell Data Banks and Phase 1 Oconee Basin Pilot Study - Trail Creek Test (Hydrologic Engineering Center 1978a; 1975). These references provide basic introductory material for the novice. The creation of a grid cell data bank for use in only hydrologic studies can be performed more simply and less precisely than is suggested by these references. The goal of this document is to present this simpler step by step approach (Figure 1 - Sequence of Tasks). Should the spatial data bank be used in a comprehensive study to store other data in addition to hydrologic and hydraulic data, a more rigorous approach to the gathering and encoding of data would be appropriate.

Several computer programs are needed in the creation of the grid cell data bank and for hydrologic modeling (Figure 2 - Data Processing Scheme). The programs needed for creation and display of the grid cell data bank are BANK and RIA (Hydrologic Engineering Center 1980; 1981b). The modeling applications programs are HYDPAR and HEC-1 (The Hydrologic Engineering Center 1978b; 1981a).

Incorporated in this document is a general overview of the data bank creation procedure and an example. The example is a model study of a portion

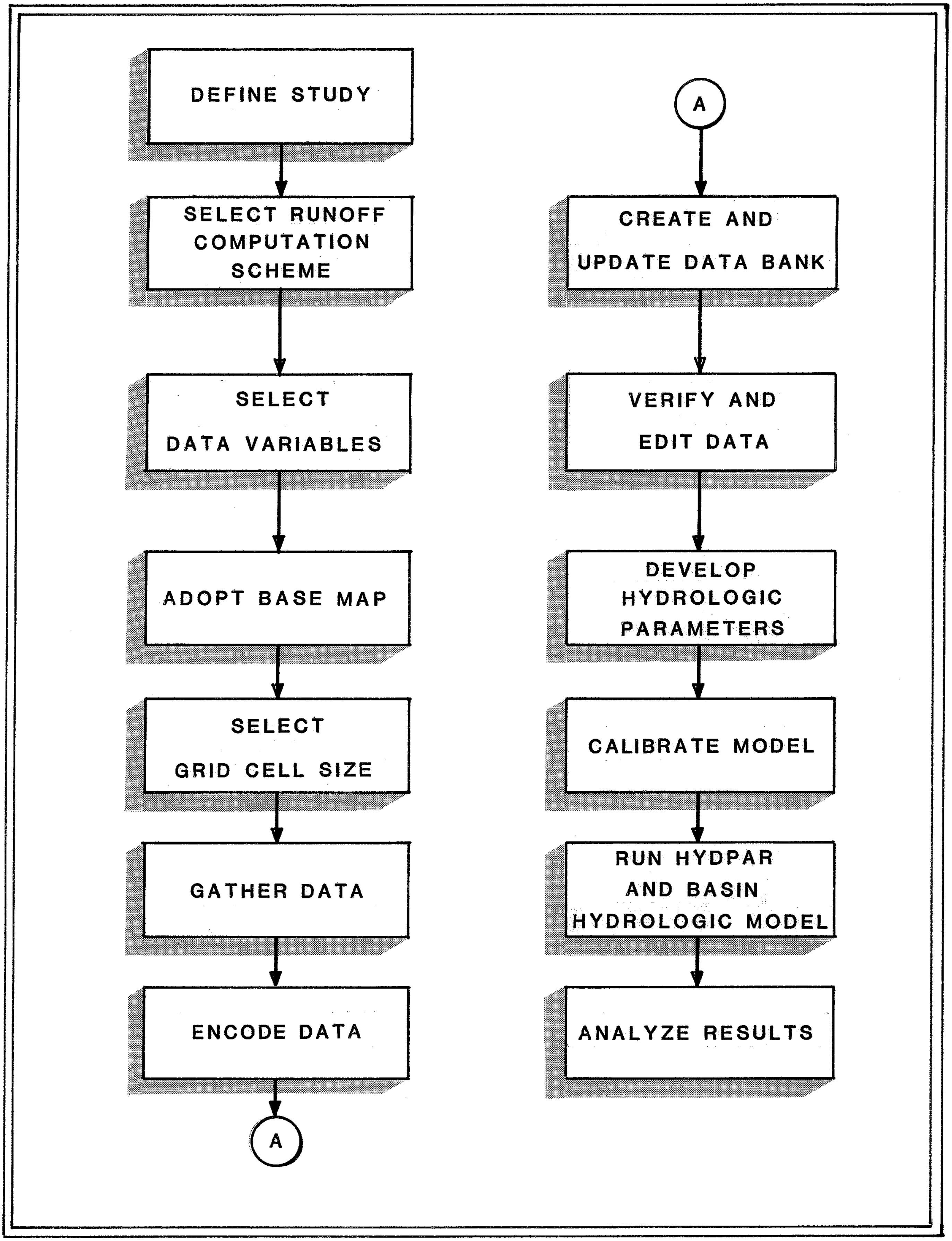

Figure 1 - Sequence of tasks

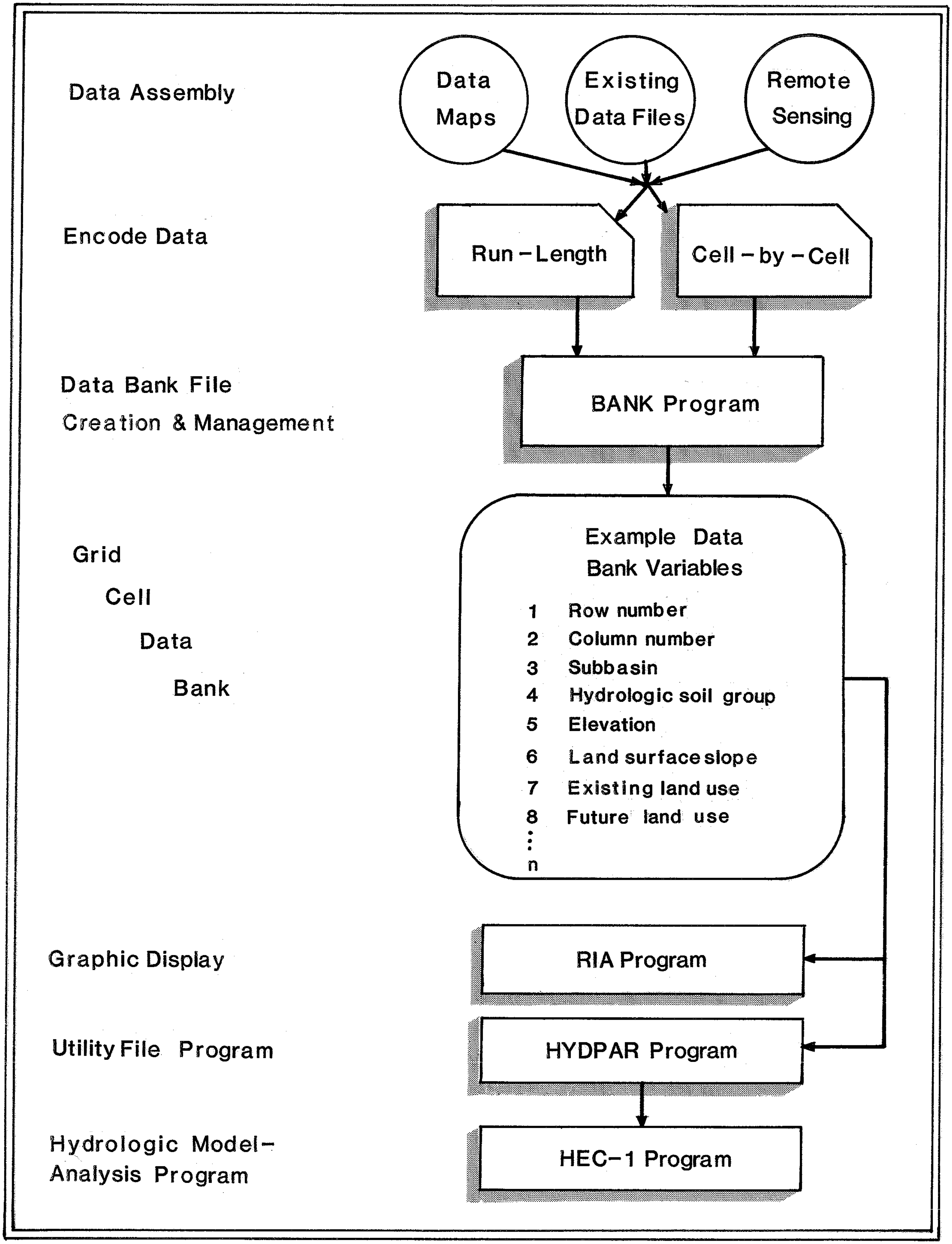

Figure 2 - Data Processing Scheme

of the Pennypack Creek watershed located near Philadelphia, Pennsylvania. Spatial data were readily available for this area, and results from hydrologic computation developed from a simple grid cell data bank were able to be compared to results obtained from detailed analysis performed in a previous study.

II. DATA BANK CREATION

The data bank creation task for hydrologic engineering yields a grid cell data file that contains the needed information, at the proper spatial resolution and scale, to perform the hydrologic computations planned. The following procedures and example provide guidance for the creation of a computer program input file that will be used for computation of flood hydrographs for historic and synthetic frequency events for existing, historic and future land use development patterns. The level of detail illustrated by the example is commensurate with that appropriate for survey (planning) investigations (e.g., final hydrology for plan formulation and evaluation) and general design memoranda.

SUMMARY OF PROCEDURE

The general strategy for determining the information to be placed in the data bank for each grid cell and for creating the data bank includes:

- Select runoff computation scheme
- Select data variables
- Adopt base map
- Select grid cell size
- Gather Data
- Encode Data
- Create and update data bank
- Verify and edit data

SELECT RUNOFF COMPUTATION SCHEME

The spatial processing program Hydrologic Parameters (HYDPAR), described in Section III, has the capability of computing loss rates by U.S. Soil Conservation Service (SCS) procedures and by weighted imperviousness. Runoff transform methods are the SCS and Snyder unit hydrograph procedures. Several other loss rate and runoff transform procedures are available with HYDPAR and should be verified with HEC prior to being used. Data variables for the SCS and percent impervious procedures are described in this document. If other methods are to be used (without using the automated data transfer capability illustrated herein), the data variables they require should be included in the data bank.

SELECT DATA VARIABLES

Data variables are the selected items of information to be stored in the data bank for each grid cell. The stored data are used by the analysis programs and are similar for all hydrologic computation procedures. The necessary data variables required by HEC-1 for the SCS and Snyder procedures are:

Subbasin boundaries (all methods)
Existing land use (land cover)* (all methods)
Hydrologic soil group (SCS method)
Land surface slope (SCS method)

It is common to include additional land use data variables for analysis of future (or past) runoff potential, e.g., year 2020 projected land use pattern. It is also quite common to include land surface elevation. Perspective computer graphic plots are often useful in interpretation of computations and for display of watershed characteristics as well as providing data from which land surface slope may be derived. Land surface slope may also be determined directly from slope maps (if they are available), from generalized soil maps (a code in the soil designation is slope class), or inferred from analysis of topographic maps.

*Land use and land cover are used herein interchangeably. Land cover as a term tends to be used more often when discussing remote sensing and vegetation classifications. It is actually cover that is revelant to hydrologic computations but historically land use has been the common terminology.

Each data variable is categorized and each category is assigned a number code. For example, the land use variable could have categories numbered as follows:

Number	Category
1	Residential Housing
2	Commercial Areas
3	Industrial Parks
4	Agricultural Land
5	Open Water Bodies

Land use should normally be grouped into 4 to 6 categories for hydrologic analysis purposes. The refinement of cataloging additional categories for hydraulic analysis purposes is unwarranted. The number and size of subbasins will depend on the size of the watershed and the hydrologic definition required for analysis. The data for soil type are given by SCS as hydrologic soil groups A through D, numbered 1 through 4 when placed in the data bank (encoded). Slope categories are encoded as numbers (starting with 1) that represent the different slope classes, e.g., 1 for 0% to 3% slope, 2 for 3% to 8% slope, etc. Slope may also be entered as the actual cell slope, if desired. Topography and other data variables that represent continuous surfaces may be encoded directly for each cell by their true value.

ADOPT BASE MAP

Map data are available in many scales, degrees of resolution, and orientations. A base map is selected in order to coordinate all map data. The base map should have a standard scale, provide the resolution required for the analysis, be oriented in a north-south direction, and have location reference points which are identifiable by latitude and longitude or state plane coordinates. A good map for most studies which meets the requirements of a base map for hydrologic analysis is the U.S. Geological Survey (USGS) 7-1/2 minute quadrangle sheet. A smaller scale map may be appropriate for regional studies with large subbasins. The quadrangle sheets provide adequate resolution at a 1-acre grid cell size (the smallest one would conceivably use), allow delineation of drainage basins, and are readily available for areas of the United States. If possible, all other map data should be redrawn at the base map scale. The alternative to redrawing is to develop compatible coordinate overlay grids at other map scales to use for encoding the variable data. This procedure is discussed later.

Data available from maps that are often considered for use in hydrologic analysis include subbasin boundaries, political boundaries, land use, soils, hydrologic soil classification, elevation, and slope. The drainage divides are generally drawn on the base map around all significant tributaries thereby defining the basin and subbasin boundaries. The subbasins may vary between 150 acres for small urban areas to 50 square miles for large basins as dictated by the study needs. The land use data are usually available from local agencies or may need to be interpreted from aerial photography. Many county or council of government planning offices have land use maps available for existing and future alternative land use patterns. Data received from local agencies or from aerial photographs are often at a useable scale and either need to be redrawn to the base map or have scaled grids developed in order to encode the data.

The hydrologic soil classification and slope (slope categories) are available on the SCS county soil survey maps. These maps are available from the SCS or state agencies for most of the United States. If the SCS slope data is unavailable, topographic elevations can be determined from the USGS quadrangle sheet and the slope calculated.

SELECT GRID CELL SIZE

For hydrologic computations a grid cell size of 10 acres has been found to be sufficient to account for definition of hydrologic variables and large enough to avoid undue effort when encoding data from the maps to the data bank (U.S. Army Engineer District, Detroit 1982). For large areas, e.g., 1,000 square miles with large subbasins of 2 to 10 square miles, a cell size larger than 25 acres has proven adequate (McKim, et al. 1983). For flood-damage computations, especially in urban areas, a cell size of one acre may be required for capturing the data required. As the cell size becomes smaller, the number of cells increases with greater time and effort required to encode the data. The determination of the grid cell size which provides adequate resolution of all data variables is an important factor in data acquisition and study costs. A concept to consider in any study is the use of a large cell size for the entire study area for hydrologic computations and perhaps other purposes (e.g., environmental) and a smaller cell size for the flood plain for damage computations (U.S. Army Engineer District, Detroit 1982). Using two cell sizes eliminates the need to encode data for the entire basin with a small cell size.

Grid cells do not need to be square. For undistorted conventional computer system line printer graphics, rectangular grid cells are required. The cell is proportional to the shape of a printer character. A pen plotter can, however, plot at any scale for any size grid cell and is the alternative to the line printer. Undistorted line printer graphics is an inexpensive, fast, and convenient way to map, verify, and display information in the data bank. For line printer graphics line printers generally operate at 10 characters per inch horizontally and at either 6 or 8 lines per inch vertically. At 6 lines per inch and using a 7-1/2 minute quadrangle sheet as the base map one character equals 1.54 acres. At 8 lines per inch one character would equal 1.148 acres. For example, a cell that measures 3 characters horizontally and 3 characters vertically for 6 lines and 8 lines per inch produces a cell size of 13.77 acres and 10.332 acres, respectively.

MAP DATA REGISTRATION AND ORIENTATION

Once the base map and cell size have been selected, the grid defining the cells should be drawn on the base map. This procedure, once performed, provides a durable grid/map product, and the grid cannot move in relation to the map. In this way possible cell registration (spatial location of a grid cell) problems are reduced. An alternative to drawing the grid directly on the map is to make an overlay. This overlay may be drawn on clear mylar, acetate, or on tracing paper so that the data to be encoded shows through the grid. Registration marks should be established so that the overlay may be carefully repositioned to avoid registration problems should it move.

The grid should be positioned on the map in a north-south orientation (e.g., aligned with UTM coordinate axes) with the origin located at a point that is easily recognizable on all maps (e.g., coordinate system point or a distinct physical feature, such as a road junction) and that allows the area of interest to be captured by the grid. An inverted cartesian coordinate system is used with the origin located in the upper left corner. This provides a row column identification for each cell starting in the upper left corner.

One method for encoding maps of different scales is to produce grids as overlays drawn proportionally larger or smaller than the base map scale. Several known reference points are required to insure that the scaled grid is positioned exactly as it is on the base map. An alternative to making an overlay is to draw the proportional grid directly on the map data to be encoded, making sure that the cells are positioned identically to those of the base map. Maps that are distorted cannot be used directly. They can be either redrawn (preferable) or encoded by a digitizer, and computer software can account for the distortion. A more detailed discussion on this topic is contained in the Guide Manual for the Creation of Grid Cell Data Banks (Hydrologic Engineering Center 1978a).

GATHER DATA

Sources of spatial data include governmental agencies, utilities, universities, and private organizations. Map data is the most readily available type of data, however, remote sensing data, e.g., aerial photographs and LANDSAT images, also can provide much of the same data.

The gathering of spatial data, along with encoding the data, is often the most costly and time consuming activity in the analysis phase of an investigation. All sources should be queried as to the availability and resolution of data. This usually will provide redundant data which can be used for validity checks. Also, a map or a data bank may be found that can be used without modification.

ENCODE DATA

Data encoding is the process by which the data is transferred from a map to the data bank. Each cell of the grid that has been placed on the base map bounds a unique area which is located by the cell's row and column numbers. For each data variable this cell has unique attributes which may or may not be the same for adjacent cells. The encoding process allows the unique attribute of each variable to be assigned to each cell and stored in the data bank by cell row and column numbers. One method for encoding data is cell by cell for each data variable. This is a lengthy process but for some data variables is an acceptable procedure. An alternative for legend type variables is cell run-length encoding wherein each variable is encoded separately and only the starting and ending columns by row are identified for each category.

The first data variable to be encoded is usually the basin/study area since all other variables should fall within this boundary. When examining a cell to determine whether it is one classification (e.g., within the study area) or another (e.g., outside the study area) usually the category which encompasses the largest portion of the cell is used. Other classification schemes are discussed in the Guide Manual for the Creation of A Grid Cell Data Bank (Hydrologic Engineering Center 1978a).

The procedure for encoding data is as follows:

1) Place the grid overlay or draw the grid on the map containing the data variable to be encoded such that the origin is located properly and the cells define/overlay the exact cells on the base map (if using the base map the grid should be drawn on the map);

2) Number the rows and columns down and to the right, respectively, from the origin;

3) Run-length encode the first row by locating the first column with a category which meets the classification requirement and then proceed to the column which last meets the category classification requirement;

4) Record on a coding sheet the row and column numbers and category number;

5) Continue on in the row until there are no more valid categories;

6) Perform steps 3 through 5 for each row in turn for this data variable;

7) Perform steps 1 through 6 for each data variable.

The exact format for preparing the computer data cards is shown in the BANK program input description (Hydrologic Engineering Center 1980). The data are placed on the U2 cards, which compose most of the program input (see Appendix A).

CREATE AND UPDATE DATA BANK

A grid cell data bank is a structured file which contains for each grid cell its unique category identification (or value) for each variable. In this step the BANK program is run using the data previously encoded as input to the program. Only one data variable is added to the grid cell data bank per run. The first run of the bank program generates and initializes the data bank and adds one variable. Each successive run of the BANK program adds another data variable. At this point it should also be noted that the BANK program can also update data variables and correct errors in the data bank.

The structure of the data bank file generated by the BANK program follows:

ROW No.	COLUMN No.	VARIABLE 3 Category No. (or value)	VARIABLE 4 Category No. (or value)	...	VARIABLE N Category No. (or value)
1	1	4	100.3	...	7
1	2	3	110.6	...	9
2	3	5	112.2	...	2
2	1	7	99.9	...	6

Where: Variable 3 could be subbasin, Variable 4 - topography, and Variable N - land use

This output file is the new or updated grid cell data bank and should be saved. It is used as input to both the RIA and HYDPAR programs.

VERIFY AND EDIT DATA

During this task the data placed in the data bank is examined and discrepancies between the original map data and the data stored are corrected. The most effective way to examine the spatial data is to have each variable plotted and then used as an overlay on the original data (base map scale), which is then evaluated for accuracy in shape and numerical content. Quite often there are voids in the plot (areas without any value) or areas which have received an incorrect value. A check is also made to insure that the entire study area has been placed in the data file. For most studies the Resource Information and Analysis (RIA) program (Hydrologic Engineering Center 1981b) which does line printer graphics is used to display each variable stored in the data bank. Errors are corrected by use of the BANK program to update the erroneous variable. When the data bank is completely verified and edited the data is then available for use by an analysis program.

III. HYDROLOGIC ANALYSIS

The hydrologic analysis is performed by two programs, HYDPAR (Hydrologic Parameters) and HEC-1 (Flood Hydrograph Package) (Hydrologic Engineering Center 1978b and 1981a). Precipitation, streamflow routings, and basin topology (control points) data for the HEC-1 watershed hydrologic model are developed in the customary manner. The parameters for the hydrograph computations are developed by HYDPAR which uses the watershed and subbasin characteristics contained in the grid cell data bank along with input coefficients for estimating the parameters for the loss rate and unit hydrograph procedure that is to be used. Trial runs are made of the two programs with the results of HYDPAR used as input to HEC-1. HEC-1 results are compared to observed values which provide guidance for the refinement of the model and the input coefficients.

HYDPAR (Hydrologic Parameters)

The HYDPAR program is the key interface between the data bank and the hydrologic computations performed by the HEC-1 program. The HYDPAR program is run using the selected runoff computation approach for the watershed status representing either the existing, historical, or future land use pattern. Data required as input to the program include the runoff relationships, stream length/slope values, and information about the form and content of the data bank. The output (printed and written to an intermediate computer file) yields subbasin runoff loss rates (SCS curve numbers or percent impervious), unit hydrograph coefficient (SCS or Snyder's lag), drainage area, and land surface slope.

The analysis procedure is to run HYDPAR for each land use condition of interest and to store the resulting hydrologic parameters in a computer file for access by HEC-1. Several conditions are easily run at this stage since the only real data change is to specify a different land use data variable in the data bank or to change the calibration relationships, if appropriate.

HEC-1 (Flood Hydrograph Package)

HEC-1 is the basic hydrologic model generally used by the Corps of Engineers for flood runoff computations. For the process described, HEC-1 is used in a customary fashion except that the hydrologic parameters needed have been derived by HYDPAR and automatically transferred to HEC-1. The parameters transferred from HYDPAR to HEC-1 through a computer file are the coefficients needed for loss rate and runoff calculations. A basic strategy for use of HEC-1 in this mode is to prepare the input data deck as described in the users manual, often for multiple plans, and specify the HYDPAR generated file(s) as the source of the hydrologic parameters (one file for each plan). The HEC-1 runs can therefore analyze historical, and/or hypothetical storm events. This procedure was used as part of the original Pennypack Creek XFPI study (Hydrologic Engineering Center 1978c).

IV. EXAMPLE

DEFINE STUDY

The Upper Pennypack Creek watershed located near Philadelphia, Pennsylvania (Figure 3), has experienced increased urban growth resulting in changed land use and drainage patterns. These changes have modified seasonal streamflow and flood peaks. The procedure described has been used to evaluate the impact of the changing land use on the rainfall-runoff process for the watershed. The 27 August 1967 storm was the storm selected for use in the model.

SELECT RUNOFF COMPUTATION SCHEME

The two procedures available were the SCS curve number - unit hydrograph procedure and the Snyder unit hydrograph procedure using percent impervious and a uniform loss rate function. The selection of the procedure to use would generally be made by an experienced hydrologic engineer based on prevailing organization practices. For this example, computations were done using both methods.

SELECT DATA VARIABLES

The data variables that were stored in the data bank to perform the hydrologic analysis desired were:

- Subbasin boundaries (both methods)
- Existing and future land use (both methods)
- Hydrologic soil group (SCS method)
- Land surface slope (SCS method)
- Grid cell elevation (not required but nice to have for displays)

The categories for each of the data variables were determined as the data that was gathered was evaluated. However, preliminary categories were identified based on existing information prior to gathering the data so that the data could be gathered in a logical and quantitative fashion.

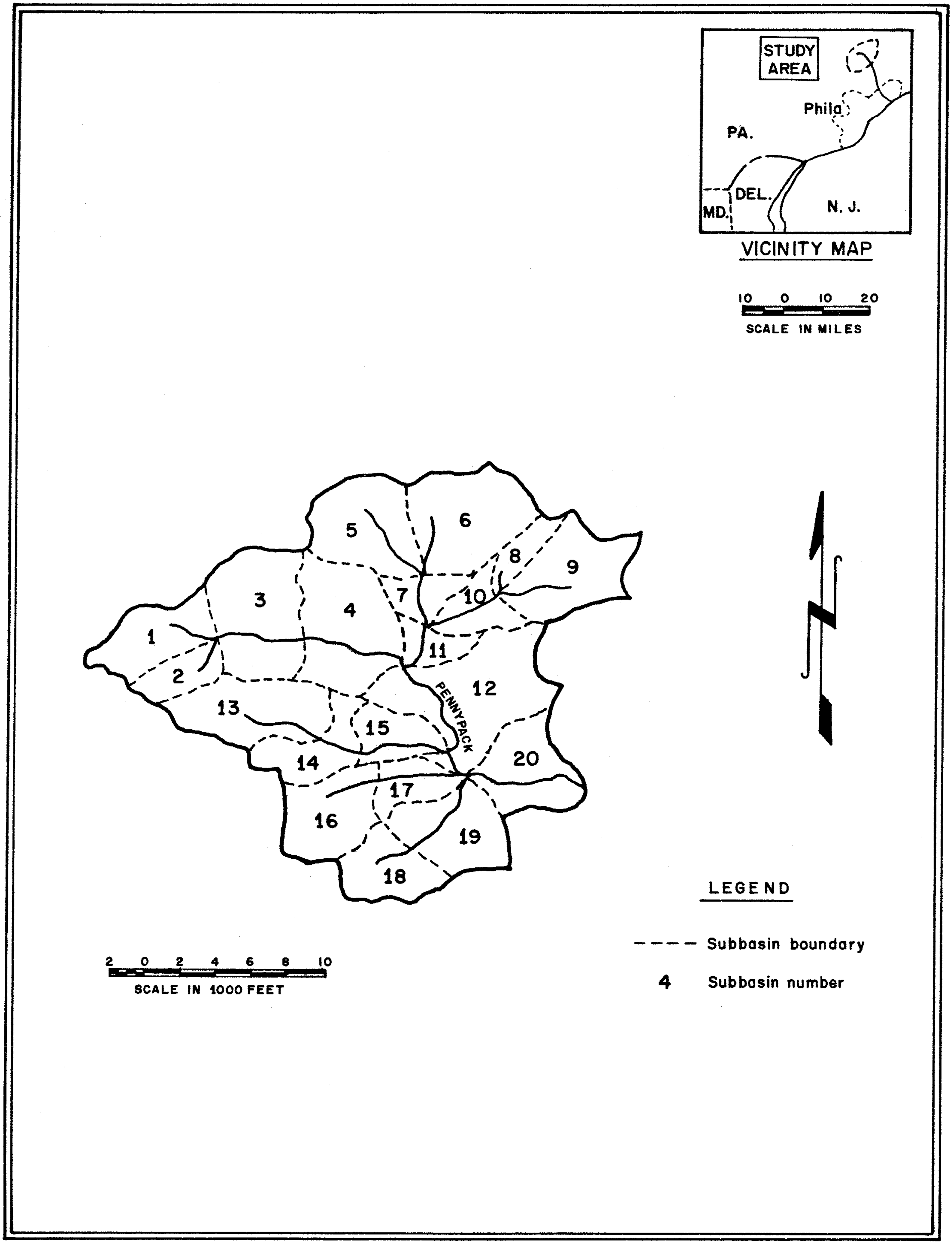

Figure 3 - Pennypack Creek - Subbasin Location Map

ADOPT BASE MAP

The USGS 7-1/2 minute quadrangle sheet was selected for the base map (Figure 4). The scale of the map (1:24000) was adequate to delineate subbasins and determine the spatial characteristics of the 10,290-acre watershed. The maps were also readily available from the USGS.

SELECT GRID CELL SIZE

The selection of the grid cell size was based on the data resolution required for the study. A 10-acre cell size was determined to provide enough definition for land use and hydrologic characteristics for the analysis. Line printer graphics was determined to be important for display and verification of the data variables. On the base map selected, a 3-character by 3-character cell at 8 lines per inch vertically and 10 characters per inch horizontally produced a cell size of 10.332 acres which was the final selection for the grid cell size. A grid was drawn at this scale on the base map with the origin located at UTM coordinate 4451000m.N., 483000m.E and the axis parallel to the UTM grid (Figure 4).

GATHER DATA

Spatial Data. The spatial data required for this example consisted of subbasins, hydrologic soil group, land surface slope, and land use patterns, both existing and future. The watershed was divided into 20 subbasins ranging in size from 0.2 square miles to 1.6 square miles. These were drawn on the base map (Figure 4). The hydrologic soil groups and the land surface slope variables were developed from SCS county soil maps which define both soil type and land surface slope. Four hydrologic soil groups were used: Group A - low runoff potential, Group B - moderate infiltration rates, Group C - slow infiltration rates, and Group D - high runoff potential. Six slopes classes were used: 0% to 3%, 3% to 8%, 8% to 15%, 15% to 25%, 25% to 50% and greater than 50% slope.

SOURCE: U.S.G.S. Topographic Maps Amber PA. and Hatboro PA.

Figure 4 - Pennypack Creek Base Map With Grid

The two land use patterns were taken from maps previously prepared by the Philadelphia District of the Corps of Engineers. The land use variable was divided into six categories: low density residential and community service; high density residential, industrial, and utilities; transportation and commercial; recreation, forest, and undeveloped; agriculture and mining; and waterbodies.

Hydrologic and Hydraulic Data. All available rain gages in the vicinity of Philadelphia were used to construct total storm isohyetal lines for the 27 August 1967 storm. Total rainfall amounts for the 20 subbasins shown in Figure 3 are tabulated in Table 1.

TABLE 1

TOTAL RAINFALL FOR 27 AUGUST 1967 STORM

Subbasin	Rain (inches)	Subbasin	Rain (inches)
1	1.10	11	1.70
2	1.20	12	1.85
3	1.25	13	1.40
4	1.50	14	1.65
5	1.30	15	1.80
6	1.60	16	1.77
7	1.62	17	1.87
8	1.75	18	2.10
9	1.93	19	2.20
10	1.75	20	2.25

The nearest recording gage was used as a pattern hyetograph. All subbasin rain totals were distributed proportionally to the pattern (Table 2).

TABLE 2

PENNYPACK CREEK PATTERN RAINFALL RECORDING
For 27 August 1967 STORM
(Incremental Values)

Time	1500	1515	1530	1545	1600	1615	1630	1645	1700	1715
Rain (inches)	0	0.10	0.45	1.45	0.73	0.02	0.80	0.50	0.25	0.05

For computations involving initial and uniform loss rates, an initial loss and a uniform loss rate were determined by trial and error reproduction of gage records at downstream locations. The best reproduction was derived using initial losses of 2.00 inches and a uniform loss rate of 1.50 inches per hour. The percent of imperviousness was based on SCS guidelines (Soil Conservation Service 1975). The adopted values are shown in Table 3. The adopted values are based on the presumption that 1/3 of the imperious area for residential land use drains onto pervious area. The losses for the SCS curve number method were calculated using SCS values selected for the specific land uses in the Pennypack Basin.

TABLE 3

PENNYPACK CREEK
RUNOFF CURVE NUMBERS*

(Antecedent Moisture Condition II and $I_a = 0.2$ S)

Land Use Category	Description	Hydrologic Soil Group A	B	C	D
1	Low Density Residential and Community Service, 28% Imperviousness	63	77	84	88
2	High Density Residential, Industrial, and Utilities, 65% Imperviousness	81	88	91	93
3	Transportation and Commercial, 75% Imperviousness	91	93	95	96
4	Recreation, Forest, and Undeveloped, 5% Imperviousness	40	62	75	81
5	Agriculture and Mining, 3% Imperviousness	70	79	84	85
6	Water Bodies, 100% Imperviousness	100	100	100	100

*Source: U.S. Army Engineer District, Philadelphia 1980.

The Snyder unit hydrograph coefficient, C_p, was calibrated by reproduction of downstream gaged records and transferred to the upper watershed by use of regression analysis derived specifically for this basin (U.S. Army Engineer District, Philadelphia 1980). The resulting regional Snyder C_p was determined to be 0.62. The Snyder t_p coefficient for each subbasin was computed by the HYDPAR program using the generalized equation (3-3), the coefficients given in Exhibit 3-2 of the HYDAR manual, and the data shown in Table 4.

TABLE 4

SNYDER UNIT HYDROGRAPH DATA

Subbasin	L (miles)	L_{ca} (miles)	S (ft/mi)
1	1.7	1.0	44
2	1.2	.5	81
3	2.0	.8	64
4	2.0	1.0	68
5	1.6	.9	52
6	1.7	.8	54
7	1.0	.5	64
8	1.2	.6	67
9	1.8	.9	66
10	1.6	.8	53
11	1.1	.5	56
12	2.9	1.3	40
13	1.9	.9	84
14	1.4	.5	90
15	1.6	.7	52
16	1.6	.8	67
17	1.6	.8	122
18	.9	.4	81
19	1.6	.9	106
20	2.2	.8	34

The referenced equation (3-3) is as follows:

$$t_p = C(X^a) * (10^{bI})$$

where t_p	=	Snyder's lag in hours
C	=	regression constant
X	=	$\frac{L * L_{ca}}{\sqrt{S}}$
L	=	characteristic stream length in miles
L_{ca}	=	length from subbasin outlet along stream channel to a point opposite the centroid of the subbasin area in miles
S	=	characteristic stream slope in feet per mile
a	=	regression coefficient
b	=	regression coefficient
I	=	imperviousness in percent

The SCS unit hydrograph lag coefficients are calculated from the following equation (generalized equation 3-2 HYDPAR Manual):

$$\text{Lag (hours)} = \frac{(L)^{0.8} \quad * \quad (S + 1)^{0.7}}{(1900) \quad * \quad (y)^{0.5}}$$

where	L	=	watercourse length from subbasin outlet to the upstream boundary which yields the longest time of travel, in feet
	y	=	average subbasin land slope in percent (computed by the HYDPAR program based on slope data for each grid cell) in percent
	S	=	(1000/CN) - 10
	CN	=	arithmetic average curve number

NOTE: L is input by the user in miles and converted to feet within the program for calculation purposes.

The magnitude of y comes directly from the data bank while the magnitude of L was manually determined by measuring the length of the main stream. Values of L are shown in Table 4. Values of L were also estimated (for verification) within an accuracy of a few thousand feet by using the following equation (Soil Conservation Service 1975):

$$L = 209\ (a)^{0.6}$$

where: a = drainage area of basin in acres

The streamflow routing data were derived using HEC-2, from which storage values for a given discharge were obtained between any two cross sections. Interpolation for routing reaches not falling exactly between two cross sections was done by locating a reach with similar length and slope and simply adopting its values. The adopted values (Hydrologic Engineering Center 1978c) were used for modified Puls routing.

ENCODE DATA

A grid containing 41 rows and 60 columns was superimposed over the watershed, as shown in Figure 4. The run length encoding scheme was used to create the input for the BANK program which was used to create the computer data bank file. The subbasins were encoded first from the base map (USGS 7-1/2 minute quadrangle sheet for Amber and Hatboro, PA) which had the grid drawn on the map. The elevation for each cell was also encoded from the base map. The hydrologic soil groups, slope, and land use data were of a different scale than that of the base map. To account for the different scale, grid overlays were made so that the overlay cells were proportional to the base map and would cover the same area on the land use, soil, and slope maps. Several points that were identifiable on all maps were selected as reference points to insure that the grid overlay would be positioned over the watershed identically to that drawn on the base map. These data variables were the run length encoded.

CREATE/UPDATE DATA BANK

The BANK program was used to create and update the data bank. The first time the program was run the initialize module was used to place -1 in each of the six variable locations assigned to each grid cell which is identified by its row and column number. Also in the first run, the update module was used to place the subbasin in the third storage location (location 1 and 2 are for the cell row and column, respectively) for each cell, thereby changing the -1 placed in that location by the initialize module to the subbasin value for the grid cell. The other five variables, hydrologic soil group, cell elevation, land surface slope, existing land use pattern (1977), and future land use pattern (2000), were entered, by use of update module, into the grid cell data variable locations 4, 5, 6, 7, and 8 respectively. The legend for the data bank is shown in Table 5 and example input and output for the BANK program are contained in Appendix A.

The output from the BANK program was saved after each run under a permanent file name in that it contains the grid cell data bank. The permanent file was then examined for errors.

VERIFY/EDIT DATA

To verify the data, line printer plots were produced and then overlaid on the base map. All the spatial variables were mapped in one execution using the mapping routine of the RIA program. The map for each variable was examined visually for errors in shape and numerical content. Several data encoding errors were identified and were corrected by use of the "update" routine of the BANK program. The RIA program was then rerun to plot the data variables that were updated. Example RIA input and output are shown in Appendix B.

DEVELOPMENT OF HYDROLOGIC PARAMETERS

The Hydrologic Parameters (HYDPAR) program was run to develop the hydrologic parameters required by HEC-1. The input data cards for HYDPAR are

TABLE 5

DATA BANK VARIABLE LEGEND

1 Cell Row Number

2 Cell Column Number

3 Pennypack Subbasins

1 - Subbasin 1
2-20 - Subbasins 2-20

4 Hydrologic Soil Groups

1 - Hydrologic Soil Group A (Low Runoff Potential)
2 - Hydrologic Soil Group B (Moderate Infiltration Rates)
3 - Hydrologic Soil Group C (Slow Infiltration Rates)
4 - Hydrologic Soil Group D (High Runoff Potential)

5 Elevation (feet m.s.l.)

6 Land Surface Slope

1 - 0 to 3 percent slope
2 - 3 to 8 percent slope
3 - 8 to 15 percent slope
4 - 15 to 25 percent slope
5 - 25 to 50 percent slope
6 - Greater than 50 percent slope

7 Existing Land Use Pattern (1977)

1 - Low Density Residential & Community Services
2 - High Density Residential, Industrial, & Utilities
3 - Transporation and Commercial
4 - Recreation, Forest, and Undeveloped
5 - Agriculture and Mining
6 - Water Body

8 Future Land Use Pattern (2000)

1 - Low Density Residential & Community Services
2 - High Density Residential, Industrial, & Utilities
3 - Transporation and Commercial
4 - Recreation, Forest, and Undeveloped
5 - Agriculture and Mining
6 - Water Body

listed in Appendix C. The slope class levels used were 0-3%, 3-8%, 8-15%, 15-25%, 25-50%, and greater than 50%. Averages for these ranges were specified on the SL card. The LU and SB cards were prepared from the data in Tables 4 and 5, respectively. Example input and output are shown in Appendix C.

The information to be transferred from HYDPAR to HEC-1 was placed in a computer file. This file was saved by appropriate specification of computer system job control instructions (JCL), retrieved by the HEC-1 JCL, and read by HEC-1. The file was also retrieved by HYDPAR so an additional plan and updates could be added to the file. Procedures for saving and retrieving a file through use of JCL are machine dependent and should be determined by consultation with ADP support staff.

EXECUTION OF BASIN HYDROLOGIC MODEL

The HEC-1 computer program was run which produced hydrographs for each subbasin. The data cards for HEC-1 are listed in Appendix D. The input rainfall data for the example are shown in Tables 1 and 2 (PG, PI, and PT cards for HEC-1). The input unit hydrograph coefficients are provided from the HYDPAR output file, and modified Puls routing criteria were used. Examples of input and output are shown in Appendix D. The procedure for reading of the HYDPAR generated file is not specifically documented in the HEC-1 users manual. It is necessary to contact HEC for the needed supplemental documentation to make use of this automated retrieval.

V. GENERAL COMMENTS

The use of spatial data management techniques for a hydrologic evaluation provides a systematic and comprehensive procedure for gathering, displaying, aggregating, and analyzing the attributes of a watershed. No predetermined or judgemental decisions have been made to the hydrologic modelling procedure by use of a spatial data management system; rather, more latitude has been allowed because many more options and variations in the coefficients and parameters used can now be evaluated very quickly and efficiently. For example, the changing of the SCS curve number or percent impervious for a particular land use or a modification of the coefficients used to compute Snyder's t_p can be accomplished by changing one input line to the HYDPAR program and then running HYDPAR and HEC-1 to obtain an answer based on the changed data. Throughout this procedure the spatial data bank does not change, thereby insuring that the basic data for all evaluations are consistent and that results are reproducible. Also, HEC-1 can evaluate several plans in the same run (HYDPAR is run once for each plan), thereby incorporating several HYDPAR output files and providing a comparison of alternatives or calibrations in one run.

Again, it should be noted that the procedure described using spatial data management techniques is to assist an experienced hydrologic engineer in performing rainfall-runoff studies. The referenced reading is recommended for those users desiring more comprehensive background in the concepts and application of grid cell data banks.

VI. REFERENCES

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VII. APPENDIXES

Appendix | | Page

APPENDIX A

BANK PROGRAM INPUT AND OUTPUT

The procedure by which data is stored in the grid cell bank is described in the text of this report. Shown here is a sample input data set and output for the BANK program which places data in the data bank. This input data set will initialize the data bank at -1 (designated on I1 card) and place values (subbasin code) contained on the U2 card (run-length encoding) in Variable 3 (designated on U1 card). The updated data bank is on TAPE 9 which must be saved. A detailed description of the data cards is contained in the BANK Users Manual (Hydrologic Engineering Center 1980).

EXAMPLE BANK INPUT

```
T1        TRAINING DOCUMENT EXAMPLE
T2          GRID CELL DATA BANK
T3          UPPER PENNYPACK CREEK
J1    1      0       0       1                 } Job Parameters
J2    1      0       8      41       60        }
I1    0     -1                                   Initialization Card
EN
U1    0      3
U2    3     28      31       5                 } Update Data cards
U2    3     35      43       6                 } for Variable 3
U2    4     26      32       5
U2    4     33      44       6
U2    5     26      32       5
U2    5     33      45       6
U2    6     25      33       5
U2    6     34      46       6
U2    6     47      48       8
U2    6     49       0       9
U2    7     25      34       5
U2    7     35      45       6
U2    7     46      47       8
U2    7     48      50       9
U2    7     53      55       9
U2    8     25      34       5
U2    8     35      44       6
U2    8     45      46
U2    8     47
U2    9
U2

        Several U2 Cards
        Not Shown For Example

                             17
                     42      19
              43     44      20
      29      50      0      20
U2    30      23     31      16
U2    30      32     43      19
U2    31      23     29      16
U2    31      30     32      18
U2    31      33     44      19
U2    32      23     29      16
U2    32      30     32      18
U2    32      33     44      19
U2    33      23     28      16
U2    33      29     33      18
U2    33      34     43      19
U2    34      28     37      18
U2    35      29     36      18
U2    36      29     35      18
EN
```

EXAMPLE BANK OUTPUT

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
UPPER PENNYPACK CREEK

J1 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   J1      1         0         0         1         0         0         0         0         0         1
```

THIS JOB WILL PERFORM THE FOLLOWING

INITIAL DATA BANKS (NINIT) = 1

DATA BANK CONVERSIONS (NCONV) = 0

DATA BANK WINDOWS (NWIND) = 0

DATA BANK UPDATES (NUP) = 1

SINGLE VARIABLE FILE UPDATES (NSVF) = 0

DATA BANK VARIABLE RECLASSIFICATIONS (NRCLAS) = 0

DATA BANK VARIANCE (NVARIA) = 0

DATA BANK DROPS (NDROP) = 0

DATA BANK FORMATS (NFORMT) = 0

THE INPUT CARD IMAGES WILL BE PRINTED

J2 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   J2      1         0         8        41        60         0
```

DATA FILE INFORMATION

THE COMPUTER FILE THE BASE DATA FILE IS ON (NFILE) = 1

THE NUMBER OF DATA VARIABLES IN THE BASE DATA FILE (NDV) = 8

THE NUMBER OF ROWS (NROWS) = 41 THE NUMBER OF COLUMNS (NCOL) = 60

THE UPDATED BASE DATA FILE WILL NOT BE PRINTED

THE BASE DATA FILE IS UNFORMATTED (NFORM) = 0

I1 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   I1      0      -1.
```

EN CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   EN
```

U1 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   U1      0        3        0       0.
```

THIS IS A ** CARD ** UPDATE

THE DATA VARIABLE UPDATED IS = 3

NO BACKGROUND VALUE (EXISTING CELL VALUE USED)

APPENDIX B

RIA PROGRAM INPUT AND OUTPUT

The RIA program plot capability (one of several major program capabilities) is used as the mapping tool for line printer graphic display of the data contained in the grid cell data bank. The RIA Users Manual (Hydrologic Engineering Center 1981b) provides a detailed description of the input required. The input and output that follow are for Variable 3 of the data bank (subbasins), which is designated on the MP Card. The symbol associated with each subbasin is input on the cards following the M4 Card and is displayed in the table following the map. Note that the M5 Card specifies that each grid cell will be 3-line printer characters wide by 3-characters high; this will provide a plot with the same scale as the base map (a USGS Quad Sheet). The plot has been reduced to fit in this document and is therefore not to that specific scale.

EXAMPLE RIA INPUT

```
T1                   TRAINING DOCUMENT EXAMPLE
T2                      GRID CELL DATA BANK
T3                     UPPER PENNY PACK CREEK
J1                                          1
J2      1       1       8       41       60       1       0     Job Parameters
J3(8F8.0)
MP      3               1        1                             Data Variable to be mapped
M2     20
M4
123456789ABCDEFGHIJKL Z                                         Map Symbols


M5      3       3
MS                                                              Map title
                TRAINING DOCUMENT EXAMPLE
                   GRID CELL DATA BANK
                  UPPER PENNYPACK CREEK
                      SUBBASIN MAP
ENDT
01
01      SB   1                                                  Symbol Titles
02
02      SB   2
03
03      SB   3
04
04      SB   4
05
05      SB   5
06
06      SB   6
07
07      SB   7
08
08      SB   8
09
09      SB   9
10
10      SB  10
11
11      SB  11
12
12      SB  12
13
13      SB  13
14
14      SB  14
15
15      SB  15
16
16      SB  16
17
17      SB  17
18
18      SB  18
19
19      SB  19
20
20      SB  20
99
ME
```

EXAMPLE RIA OUTPUT

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
UPPER PENNY PACK CREEK

J1 CARD

```
CC 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
   J1      0         0         0         0         1
```

THIS JOB WILL PERFORM THE FOLLOWING

NUMBER OF DISTANCE DETERMINATIONS (NSRCH) = 0

NUMBER OF IMPACT ASSESSMENTS (NIM) = 0

NUMBER OF ATTRACTIVENESS MODELS (NAM) = 0

NUMBER OF COINCIDENTS TABULATIONS (NCOMB) = 0

NUMBER OF MAPS FROM THE DATA FILE (NGRPH) = 1

J2 CARD

```
CC 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
   J2      1         1         8        41        60         1         0
```

DATA FILE INFORMATION

THE COMPUTER FILE THE BASE DATA FILE IS ON (NFILE) = 1

THE NUMBER OF DATA VARIABLES IN THE BASE DATA FILE (NDV) = 8

THE NUMBER OF DATA VARIABLES IN THE WORKING DATA FILE (NN) = 8

THE NUMBER OF ROWS (NROWS) = 41 THE NUMBER OF COLUMNS (NCOL) = 60

THE WORKING DATA FILE WILL BE CREATED (NSKIP) = 1

THE BASE DATA FILE IS FORMATTED (NFORM) = 1

J3 CARD

```
CC 1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
   J3(8F8.0)
```

```
***********************************************
*                                             *
*              X   X  XXX  XXXX               *
*              XX XX X   X X   X              *
*              X X X X   X XXXX               *
*              X   X XXXXX X                  *
*              X   X X   X X                  *
*                                             *
*  XXXX   XXX   XXX  X   X  XXX   XXX  XXXXX  *
*  X   X X   X X   X X  X  X   X X   X X      *
*  XXXX  X   X X     XXX   X   X X     XXX    *
*  X     XXXXX X   X X  X  XXXXX X  XX X      *
*  X     X   X  XXX  X   X X   X  XXXX XXXXX  *
*                                             *
***********************************************
```

MP CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   MP     3       0       1       1
```

DATA VARIABLE MAPPED (NVAR) = 3

MINIMUM VALUE MAPPED (MINV) = 0

SUBLEVEL TEXT FLAG (ISUBT) = 1

LINE CARRIAGE CONTROL (LCAR) = 1

M2 OPTION(LEVELS)

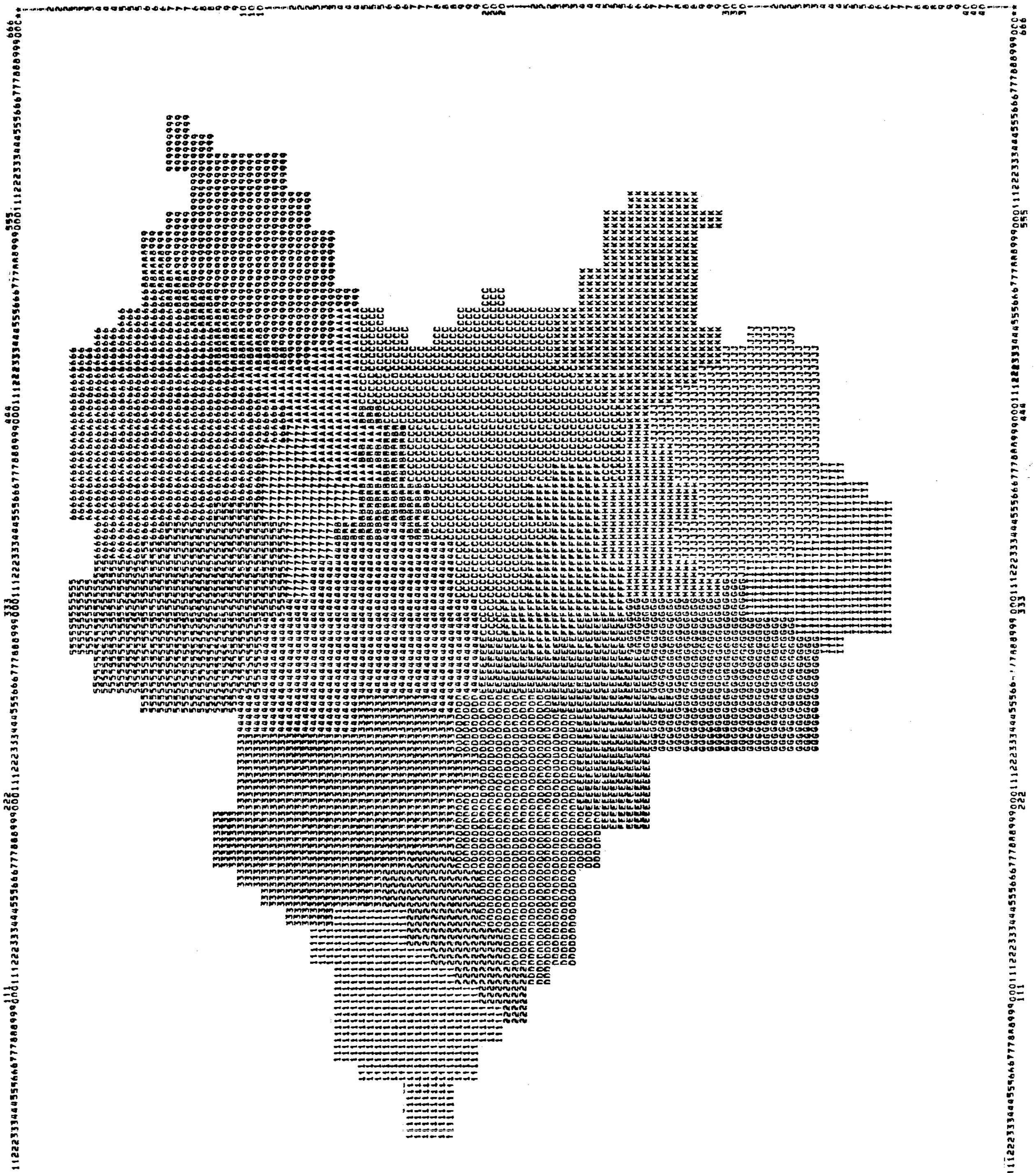
NUMBER OF MAP LEVELS = 20

M4 OPTION(SYMBOLS)

```
                                    1                   2
LEVEL        1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
             - - - - - - - - - - - - - - - - - - - - - - - - -
OVERPRINT1   1 2 3 4 5 6 7 8 9 A B C D E F G H I J K L   Z
OVERPRINT2
OVERPRINT3
OVERPRINT4
```

M5 OPTION(CELL SIZE)

CELL SIZE IS 3 CHARACTERS DOWN AND 3 CHARACTERS ACROSS



Reduced, Not to Scale

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
UPPER PENNYPACK CREEK
SUBBASIN MAP

DATA VALUE EXTREMES ARE 1.000 20.000

LEVEL NUMBER	SYMBOL	VALUE RANGE	PERCENT VALUE RANGE	NO. CELLS	PERCENTILE RANGE	PERCENT OF AREAS	
	11111111	1.000			0.00		
1	11111111		5.00	54		5.42	SB 1
	11111111	1.950			5.42		
	22222222	1.950			5.42		
2	22222222		5.00	26		2.61	SB 2
	22222222	2.900			8.03		
	33333333	2.900			8.03		
3	33333333		5.00	86		8.63	SB 3
	33333333	3.850			16.67		
	44444444	3.850			16.67		
4	44444444		5.00	73		7.33	SB 4
	44444444	4.800			24.00		
	55555555	4.800			24.00		
5	55555555		5.00	73		7.33	SB 5
	55555555	5.750			31.33		
	66666666	5.750			31.33		
6	66666666		5.00	83		8.33	SB 6
	66666666	6.700			39.66		
	77777777	6.700			39.66		
7	77777777		5.00	20		2.01	SB 7
	77777777	7.650			41.67		
	88888888	7.650			41.67		
8	88888888		5.00	12		1.20	SB 8
	88888888	8.600			42.87		
	99999999	8.600			42.87		
9	99999999		5.00	58		5.82	SB 9
	99999999	9.550			48.69		
	AAAAAAAA	9.550			48.69		
10	AAAAAAAA		5.00	23		2.31	SB 10
	AAAAAAAA	10.500			51.00		

	BBBBBBBB	10.500			51.00		
11	BBBBBBBB		5.00	14		1.41	SB 11
	BBBBBBBB	11.450			52.41		
	CCCCCCCC	11.450			52.41		
12	CCCCCCCC		5.00	99		9.94	SB 12
	CCCCCCCC	12.400			62.35		
	DDDDDDDD	12.400			62.35		
13	DDDDDDDD		5.00	64		6.43	SB 13
	DDDDDDDD	13.350			68.78		
	EEEEEEEE	13.350			68.78		
14	EEEEEEEE		5.00	43		4.32	SB 14
	EEEEEEEE	14.300			73.09		
	FFFFFFFF	14.300			73.09		
15	FFFFFFFF		5.00	30		3.01	SB 15
	FFFFFFFF	15.250			76.10		
	GGGGGGGG	15.250			76.10		
16	GGGGGGGG		5.00	55		5.52	SB 16
	GGGGGGGG	16.200			81.63		
	HHHHHHHH	16.200			81.63		
17	HHHHHHHH		5.00	26		2.61	SB 17
	HHHHHHHH	17.150			84.24		
	IIIIIIII	17.150			84.24		
18	IIIIIIII		5.00	36		3.61	SB 18
	IIIIIIII	18.100			87.85		
	JJJJJJJJ	18.100			87.85		
19	JJJJJJJJ		5.00	66		6.63	SB 19
	JJJJJJJJ	19.050			94.48		
	KKKKKKKK	19.050			94.48		
20	KKKKKKKK		5.00	55		5.52	SB 20
	KKKKKKKK	20.000			100.00		

APPENDIX C

HYDPAR PROGRAM INPUT AND OUTPUT

The HYDPAR program accesses the grid cell data bank and uses the retrieved information along with the input data to develop hydrologic parameters. The data required by the program is described in the text of this document and in the HYDPAR Users Manual (Hydrologic Engineering Center 1981b).

The HYDPAR run shown is for the SCS Curve Number procedure and for existing land use conditions. The data variables used are 3, 4, 6, and 7 which are subbasin, hydrologic soil group, land surface slope, and existing land use, respectively. The hydrologic parameters developed for transfer to HEC-1 are by subbasin and include drainage area, average curve number, subbasin lag, and the hydrologic procedure for which the parameters were developed.

EXAMPLE HYDPAR INPUT

```
T1       TRAINING DOCUMENT EXAMPLE                                          Title Cards
T2          GRID CELL DATA BANK
T3                  HYDPAR
J1      0       1       1      41     6010.33508                            Job
J2      8      20       3       6       7       6       6       4           Parameters
ZW TRAINING DOC EXIST. LAND USE - SCS
FT(8F8.0)
SL    1.5     5.5    11.5      20    37.5      60                           Slope Classes
LU      1      63      77      84      88        LD RESID & COMMUN SERV
LU      2      81      88      91      93        HD RESID, INDUST & UTIL    Curve Numbers
LU      3      91      93      95      96        TRANSPORT & COMMERCIAL     by Land Use
LU      4      40      62      75      81        RECREAT, FOREST & UNDEV
LU      5      70      79      84      85        AGRICULTURE & MINING
LU      6     100     100     100     100        WATER BODY
SB     01     1.7                   SB 1
SB     02     1.2                   SB 2
SB     03     2.0                   SB 3
SB     04     2.0                   SB 4
SB     05     1.6                   SB 5
SB     06     1.7                   SB 6
SB     07     1.0                   SB 7
SB     08     1.2                   SB 8
SB     09     1.8                   SB 9
SB     10     1.6                   SB 10                  Subbasin
SB     11     1.1                   SB 11                  Characteristics
SB     12     2.9                   SB 12
SB     13     1.9                   SB 13
SB     14     1.4                   SB 14
SB     15     1.6                   SB 15
SB     16     1.6                   SB 16
SB     17     1.6                   SB 17
SB     18      .9                   SB 18
SB     19     1.6                   SB 19
SB     20     2.2                   SB 20
END
```

EXAMPLE HYDPAR OUTPUT

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
HYDPAR

J1 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   J1      0       1       1      41      60   10.34
```

J1 JOB PARAMETERS

```
IANL   =       0, CURVE NUMBER AND SCS LAG WILL BE COMPUTED FOR EACH SUBBASIN

ILUPRT =       1, LIST INPUT CARDS + NORMAL PRINTOUT

IFMT   =       1, GRID CELL DATA BANK IS FORMATTED

NROW   =      41, TOTAL NUMBER OF ROWS IN DATA BANK

NCOL   =      60, TOTAL NUMBER OF COLUMNS IN DATA BANK

SIZE   =   10.34, THE SIZE OF THE GRID CELL IS IN ACRES
```

J2 CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   J2      8      20       3       6       7       6       6       4
```

J2 JOB PARAMETERS

```
NVAR   =       8, THE NUMBER OF DATA VARIABLES PER GRID CELL RECORD

NSUB   =      20, THE NUMBER OF SUBBASINS ANALYZED IN THIS RUN

IBS    =       3, IS THE SEQUENCE NUMBER OF THE DATA BANK WHICH IS THE SUBBASIN
                  CODE
NLUSE  =       6, THE NUMBER OF LAND USE CATEGORIES IN THE GRID CELL DATA BANK

ILD    =       7, IS THE SEQUENCE NUMBER OF THE DATA BANK WHICH IS THE LAND USE
                  PATTERN TO BE ANALYZED
NSLP   =       6, THE NUMBER OF SLOPE CLASSES FOR CURVE NUMBER ANALYSIS

ISLP   =       6, IS THE SEQUENCE NUMBER OF THE DATA BANK WHICH IS THE SCS LAND
                  SURFACE SLOPE CODE
IHYO   =       4, IS THE SEQUENCE NUMBER OF THE DATA BANK WHICH IS THE HYDROLOGIC
                  SOIL GROUP CODE
```

HECDSS WRITE CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   ZW TRAINING DOC EXIST. LAND USE - SCS
```

FILE SYSTEM INFORMATION - A FILE WILL BE CREATED TO PASS HYDROLOGIC PARAMETERS TO HEC-1 USING THE HEC DATA STORAGE SYSTEM

```
PROJ    =     TRAINING DOC

ALT     =    EXIST. LAND USE - SCS

IYR     =

--DSS---ZOPEN  EMPTY FILE OPENED   71
```

FORMAT CARD

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   FT(8F8.0)
```

LAG EQUATION

****

$$\text{LAG (HOURS)} = \frac{(L)^{0.8}\,(S+1)^{0.7}}{(1900)(Y)^{0.5}}$$

WHERE --

L = THE HYDRAULIC LENGTH OF WATERSHED IN FEET

Y = AVERAGE SUBBASIN LAND SLOPE IN PER CENT

S = (1000/CN)-10
WHERE CN IS THE CURVE NUMBER

THE SUBBASIN CURVE NUMBER IS A WEIGHTED AVERAGE FOR THE LAND USE WITHIN THE HYDROLOGIC SOIL GROUPS. SUBBASIN SLOPE IS A SIMPLE AVERAGE AND SUBBASIN STREAM SLOPE AND LENGTH ARE DETERMINED EXTERNALLY AND DIRECTLY INPUT.

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
HYDPAR

SLOPE CLASS AVERAGES

CC	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
SL	2.	6.	12.	20.	38.	60.	0.	0.	0.	0.

SLOPE CLASS	AVERAGE PERCENT
1	1.500
2	5.500
3	11.500
4	20.000
5	37.500
6	60.000

LAND USE CATEGORIES

CC	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
LU	1	63.	77.	84.	88.	0.LD RESID & COMMUN SERV		
LU	2	81.	88.	91.	93.	0.HD RESID, INDUST & UTIL		
LU	3	91.	93.	95.	96.	0.TRANSPORT & COMMERCIAL		
LU	4	40.	62.	75.	81.	0.RECREAT, FOREST & UNDEV		
LU	5	70.	79.	84.	85.	0.AGRICULTURE & MINING		
LU	6	100.	100.	100.	100.	0.WATER BODY		

CURVE NUMBER SUMMARY WITH ASSOCIATED LAND USE CATEGORIES

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL GROUP A	B	C	D
1	LD RESID & COMMUN SERV	63.	77.	84.	88.
2	HD RESID, INDUST & UTIL	81.	88.	91.	93.
3	TRANSPORT & COMMERCIAL	91.	93.	95.	96.
4	RECREAT, FOREST & UNDEV	40.	62.	75.	81.
5	AGRICULTURE & MINING	70.	79.	84.	85.
6	WATER BODY	100.	100.	100.	100.

SUBBASIN PARAMETER CARDS

```
CC 12345678901234567890123456789012345678901234567890123456789012345678901234567890
   SB     1.     1.70    0.00     0.0    SB 1     0.00
   SB     2.     1.20    0.00     0.0    SB 2     0.00
   SB     3.     2.00    0.00     0.0    SB 3     0.00
   SB     4.     2.00    0.00     0.0    SB 4     0.00
   SB     5.     1.60    0.00     0.0    SB 5     0.00
   SB     6.     1.70    0.00     0.0    SB 6     0.00
   SB     7.     1.00    0.00     0.0    SB 7     0.00
   SB     8.     1.20    0.00     0.0    SB 8     0.00
   SB     9.     1.80    0.00     0.0    SB 9     0.00
   SB    10.     1.60    0.00     0.0   SB 10     0.00
   SB    11.     1.10    0.00     0.0   SB 11     0.00
   SB    12.     2.90    0.00     0.0   SB 12     0.00
   SB    13.     1.90    0.00     0.0   SB 13     0.00
   SB    14.     1.40    0.00     0.0   SB 14     0.00
   SB    15.     1.60    0.00     0.0   SB 15     0.00
   SB    16.     1.60    0.00     0.0   SB 16     0.00
   SB    17.     1.60    0.00     0.0   SB 17     0.00
   SB    18.     0.90    0.00     0.0   SB 18     0.00
   SB    19.     1.60    0.00     0.0   SB 19     0.00
   SB    20.     2.20    0.00     0.0   SB 20     0.00
```

SUBBASIN SUMMARY TABLE

HYDPAR SUBBASIN	STREAM LENGTH (MILES)	LENGTH TO CENTROID (MILES)	STREAM SLOPE (FT./MI.)	HEC-1 STATION	SNYDER"S CP
1.	1.70	0.00	0.0	SB 1	0.00
2.	1.20	0.00	0.0	SB 2	0.00
3.	2.00	0.00	0.0	SB 3	0.00
4.	2.00	0.00	0.0	SB 4	0.00
5.	1.60	0.00	0.0	SB 5	0.00
6.	1.70	0.00	0.0	SB 6	0.00
7.	1.00	0.00	0.0	SB 7	0.00
8.	1.20	0.00	0.0	SB 8	0.00
9.	1.80	0.00	0.0	SB 9	0.00
10.	1.60	0.00	0.0	SB 10	0.00
11.	1.10	0.00	0.0	SB 11	0.00
12.	2.90	0.00	0.0	SB 12	0.00
13.	1.90	0.00	0.0	SB 13	0.00
14.	1.40	0.00	0.0	SB 14	0.00
15.	1.60	0.00	0.0	SB 15	0.00
16.	1.60	0.00	0.0	SB 16	0.00
17.	1.60	0.00	0.0	SB 17	0.00
18.	0.90	0.00	0.0	SB 18	0.00
19.	1.60	0.00	0.0	SB 19	0.00
20.	2.20	0.00	0.0	SB 20	0.00

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
HYDPAR

SUBBASIN 1.

LAND USE CATEGORY	LAND USE	AVE CURVE NO.	SURFACE SLOPE (PERCENT)	AREA IN ACRES	PERCENT OF SUBBASIN
1	LD RESID & COMMUN SERV	81.7	6.60	248.04	44.44
4	RECREAT, FOREST & UNDEV	73.7	6.70	103.35	18.52
5	AGRICULTURE & MINING	81.8	5.80	206.70	37.04
	SUBBASIN AVERAGE	80.3	6.32	558.09	

```
****************************************
*          SUBBASIN    1. DATA          *
*--------------------------------------*
* DRAINAGE AREA (ACRES)     =    558.09 *
* DRAINAGE AREA (SQ. MI.)   =      0.87 *
* STREAM LENGTH (MILES)     =      1.70 *
* SUBBASIN SLOPE (PERCENT)  =      6.32 *
* AVERAGE CURVE NUMBER      =     80.28 *
* SUBBASIN LAG (HOURS)      =      0.72 *
* NUMBER OF DATA CELLS      =     54.00 *
*                                      *
****************************************
```

Subbasins 2-20
Not shown

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
HYDPAR

SUMMARY OF SUBBASIN DATA

SUBBASIN NUMBER	DRAINAGE AREA (SQ. MI.)	PERCENT OF WATERSHED	AVERAGE CURVE NUMBER	SUBBASIN LAG (HOURS)	STREAM LENGTH (MILES)	SUBBASIN SLOPE (PERCENT)
1.	0.87	5.42	80.3	0.72	1.70	6.32
2.	0.42	2.61	78.2	0.55	1.20	7.12
3.	1.39	8.63	80.3	0.78	2.00	7.13
4.	1.18	7.33	84.5	0.68	2.00	7.06
5.	1.18	7.33	82.8	0.68	1.60	5.50
6.	1.34	8.33	79.9	0.84	1.70	4.83
7.	0.32	2.01	84.1	0.40	1.00	7.00
8.	0.19	1.20	85.1	0.54	1.20	4.83
9.	0.94	5.82	82.4	0.75	1.80	5.71
10.	0.37	2.31	85.6	0.58	1.60	6.28
11.	0.23	1.41	85.4	0.42	1.10	6.79
12.	1.60	9.94	83.5	0.92	2.90	7.44
13.	1.03	6.43	82.3	0.75	1.90	6.16
14.	0.69	4.32	81.9	0.54	1.40	7.59
15.	0.48	3.01	87.1	0.48	1.60	8.10
16.	0.89	5.52	82.8	0.59	1.60	7.40
17.	0.42	2.61	78.8	0.54	1.60	11.23
18.	0.58	3.61	75.8	0.43	0.90	8.40
19.	1.07	6.63	77.2	0.56	1.60	11.61
20.	0.89	5.52	77.9	0.77	2.20	9.70

TRAINING DOCUMENT EXAMPLE
GRID CELL DATA BANK
HYDPAR

DATA FOR USE BY HEC-1 THROUGH HECDSS

HEC-1 STATION	DRAINAGE AREA (SQ.MI.)	SUBBASIN CURVE NUMBER	SUBBASIN LAG (HOURS)	SUBBASIN PERCENT IMPERV.	SNYDER"S LAG (TP) (HOURS)	SNYDER"S PEAKING COEF(CP)	HYDRO-GRAPH METHOD
SB 1	0.87	80.28	0.72	0.00	0.00	0.00	SCS CN
SB 2	0.42	78.23	0.55	0.00	0.00	0.00	SCS CN
SB 3	1.39	80.28	0.78	0.00	0.00	0.00	SCS CN
SB 4	1.18	84.53	0.68	0.00	0.00	0.00	SCS CN
SB 5	1.18	82.75	0.68	0.00	0.00	0.00	SCS CN
SB 6	1.34	79.89	0.84	0.00	0.00	0.00	SCS CN
SB 7	0.32	84.10	0.40	0.00	0.00	0.00	SCS CN
SB 8	0.19	85.08	0.54	0.00	0.00	0.00	SCS CN
SB 9	0.94	82.36	0.75	0.00	0.00	0.00	SCS CN
SB 10	0.37	85.61	0.58	0.00	0.00	0.00	SCS CN
SB 11	0.23	85.36	0.42	0.00	0.00	0.00	SCS CN
SB 12	1.60	83.54	0.92	0.00	0.00	0.00	SCS CN
SB 13	1.03	82.30	0.75	0.00	0.00	0.00	SCS CN
SB 14	0.69	81.88	0.54	0.00	0.00	0.00	SCS CN
SB 15	0.48	87.10	0.48	0.00	0.00	0.00	SCS CN
SB 16	0.89	82.82	0.59	0.00	0.00	0.00	SCS CN
SB 17	0.42	78.77	0.54	0.00	0.00	0.00	SCS CN
SB 18	0.58	75.81	0.43	0.00	0.00	0.00	SCS CN
SB 19	1.07	77.21	0.56	0.00	0.00	0.00	SCS CN
SB 20	0.89	77.89	0.77	0.00	0.00	0.00	SCS CN

```
     HECDSS FILE INFORMATION                  HECDSS PATHNAMES FOR USE BY HEC-1
     -----------------------                  ---------------------------------

--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 1/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 2/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 3/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 4/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 5/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 6/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 7/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 8/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 9/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 10/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 11/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 12/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 13/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 14/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 15/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 16/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 17/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 18/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 19/HYDPAR///EXIST. LAND USE - SCS/
--DSS---ZWRITE FILE   71, VERS.   1   /TRAINING DOC/SB 20/HYDPAR///EXIST. LAND USE - SCS/

                  --DSS---ZCLOSE FILE   71
                            NO. RECORDS=        20
                            FILE SIZE=        2550 WORDS,        23 SECTORS
                            PERCENT INACTIVE=  0.00


+++++++++++++++++++
END OF RUN
HYDPAR PROGRAM STOP
+++++++++++++++++++
```

APPENDIX D

HEC-1 PROGRAM INPUT AND OUTPUT

The HEC-1 program is the generalized flood hydrograph package used to model the basin. An input listing, annotated to show data storage system read capabilities, and output display for Subbasin 1 are shown on the following pages. It is not the intention of this document to provide guidance on the use or calibration of the HEC-1 basin model. The HEC-1 Users Manual (Hydrologic Engineer Center 1981a) describes the program's capabilities and input requirements. Other guidance documents that describe the scope of HEC-1 capabilities in project investigations are available from HEC. The HEC should be contacted prior to implementing these options to obtain the most up to date procedures and guidance.

EXAMPLE HEC-1 INPUT

```
ID          TRAINING DOCUMENT EXAMPLE
ID             GRID CELL DATA BANK
ID                    HEC-1
IT     15 27AUG67     1145       60
IN     15 27AUG67     1145
IO
JP      2
PG      1     1.10       1
PG      2     1.20       1
PG      3     1.25       1
PG      4     1.50       1
PG      5     1.30       1
PG      6     1.60       1
PG      7     1.62       1
PG      8     1.75       1
PG      9     1.93       1
PG     10     1.75       1
PG     11     1.70       1
PG     12     1.85       1
PG     13     1.40       1
PG     14     1.65       1
PG     15     1.80       1
PG     16     1.77       1
PG     17     1.87       1
PG     18     2.10       1
PG     19     2.20       1
PG     20     2.25       1
PG    300
PI    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
PI    .00      .00      .00      .10      .45     1.45      .73      .02      .80      .50
PI    .25      .05      .00      .00      .00      .00      .00      .00      .00      .00
PI    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
PI    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
KK  SB 1   RF-RO FOR SB 1                                             Subbasin Identification
KP      1                                                             Plan
ZR TRAINING DOC EXIST. LAND USE - SCS                      BZ         DSS Pathname
PT      1
PR    300                                                             BZ replaces BA thereby
BZ                                                                    indicating that data
BF   -1.5     -.25     1.38                                           is to be read from the
KP      2                                                             DSS.
ZR TRAINING DOC FUTURE LAND USE - SCS                      BZ
BZ
```

Input for subbasins
2 through 20 not shown

```
KK SB 20 COMBINE SB 1-20
HC      2
ZZ
```

Note: No loss rate cards are included for the SCS method . .
Parameters are read from the DSS.

EXAMPLE HEC-1 OUTPUT

```
                         TRAINING DOCUMENT EXAMPLE
                            GRID CELL DATA BANK
                                   HEC-1

 6 IO         OUTPUT CONTROL VARIABLES
                    IPRNT           0  PRINT CONTROL
                    IPLOT           0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE

 5 IN         TIME DATA FOR INPUT TIME SERIES
                    JXMIN          15  TIME INTERVAL IN MINUTES
                   JXDATE     27AUG67  STARTING DATE
                   JXTIME        1145  STARTING TIME

   IT         HYDROGRAPH TIME DATA
                     NMIN          15  MINUTES IN COMPUTATION INTERVAL
                    IDATE     27AUG67  STARTING DATE
                    ITIME        1145  STARTING TIME
                       NQ          60  NUMBER OF HYDROGRAPH ORDINATES
                   NDDATE     28AUG67  ENDING DATE
                   NDTIME        0230  ENDING TIME

                COMPUTATION INTERVAL    0.25 HOURS
                     TOTAL TIME BASE   14.75 HOURS

        ENGLISH UNITS
             DRAINAGE AREA         SQUARE MILES
             PRECIPITATION DEPTH   INCHES
             LENGTH. ELEVATION     FEET
             FLOW                  CUBIC FEET PER SECOND
             STORAGE VOLUME        ACRE-FEET
             SURFACE AREA          ACRES
             TEMPERATURE           DEGREES FAHRENHEIT

   JP         MULTI-PLAN OPTION
                    NPLAN           2  NUMBER OF PLANS

   JR         MULTI-RATIO OPTION
                  RATIOS OF RUNOFF
                 1.00

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
                  **************
                  *            *
  34 KK           *     SB 1   *         RF-RO FOR SB 1
                  *            *
                  **************


***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

  35 KP        PLAN  1 FOR STATION     SB 1             RF-RO FOR SB 1
                  -----DSS---ZOPEN NONEMPTY FILE OPENED   71   0000R10C*TD21DSS
-----DSS--- ZREAD FILE  71.  VERS.  3   /TRAINING DOC/SB 1/HYDPAR///EXIST. LAND USE - SCS/

               SUBBASIN RUNOFF DATA

  39 BA          SUBBASIN CHARACTERISTICS
                       TAREA         0.87  SUBBASIN AREA

  40 BF          BASE FLOW CHARACTERISTICS
                       STRTQ         1.31  INITIAL FLOW
                       QRCSN        -0.25  BEGIN BASE FLOW RECESSION
                       RTIOR      1.38000  RECESSION CONSTANT

                 PRECIPITATION DATA

  37 PT           TOTAL STORM STATIONS         1
   0 PW                        WEIGHTS      1.00

  38 PR             RECORDING STATIONS       300
   0 PW                        WEIGHTS      1.00

  39 LS          SCS LOSS RATE
                       STRTL         0.49  INITIAL ABSTRACTION
                      CRVNBR        80.28  CURVE NUMBER
                       RTIMP         0.00  PERCENT IMPERVIOUS AREA

  39 UD          SCS DIMENSIONLESS UNITGRAPH
                        TLAG         0.72  LAG

                                                                          ***
```

PRECIPITATION STATION DATA

STATION	TOTAL	AVG. ANNUAL	WEIGHT
1	1.10	1.00	1.00

TEMPORAL DISTRIBUTIONS

STATION 300. WEIGHT = 1.00

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.45	1.45	0.73	0.02	0.80	0.50
0.25	0.05								

UNIT HYDROGRAPH
16 END-OF-PERIOD ORDINATES

91.	316.	485.	467.	351.	205.	128.	80.	49.	30.
19.	12.	7.	5.	3.	1.				

****

HYDROGRAPH AT STATION SB 1

DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	*	DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
27	AUG	1145	1	0.00	0.00	0.00	1.	*	27	AUG	1915	31	0.00	0.00	0.00	9.
27	AUG	1200	2	0.00	0.00	0.00	1.	*	27	AUG	1930	32	0.00	0.00	0.00	8.
27	AUG	1215	3	0.00	0.00	0.00	1.	*	27	AUG	1945	33	0.00	0.00	0.00	8.
27	AUG	1230	4	0.00	0.00	0.00	1.	*	27	AUG	2000	34	0.00	0.00	0.00	7.
27	AUG	1245	5	0.00	0.00	0.00	1.	*	27	AUG	2015	35	0.00	0.00	0.00	7.
27	AUG	1300	6	0.00	0.00	0.00	1.	*	27	AUG	2030	36	0.00	0.00	0.00	6.
27	AUG	1315	7	0.00	0.00	0.00	1.	*	27	AUG	2045	37	0.00	0.00	0.00	6.
27	AUG	1330	8	0.00	0.00	0.00	1.	*	27	AUG	2100	38	0.00	0.00	0.00	5.
27	AUG	1345	9	0.00	0.00	0.00	1.	*	27	AUG	2115	39	0.00	0.00	0.00	5.
27	AUG	1400	10	0.00	0.00	0.00	1.	*	27	AUG	2130	40	0.00	0.00	0.00	4.
27	AUG	1415	11	0.00	0.00	0.00	1.	*	27	AUG	2145	41	0.00	0.00	0.00	4.
27	AUG	1430	12	0.00	0.00	0.00	1.	*	27	AUG	2200	42	0.00	0.00	0.00	4.
27	AUG	1445	13	0.00	0.00	0.00	0.	*	27	AUG	2215	43	0.00	0.00	0.00	3.
27	AUG	1500	14	0.00	0.00	0.00	0.	*	27	AUG	2230	44	0.00	0.00	0.00	3.
27	AUG	1515	15	0.03	0.03	0.00	0.	*	27	AUG	2245	45	0.00	0.00	0.00	3.
27	AUG	1530	16	0.11	0.11	0.00	0.	*	27	AUG	2300	46	0.00	0.00	0.00	3.
27	AUG	1545	17	0.37	0.37	0.00	0.	*	27	AUG	2315	47	0.00	0.00	0.00	3.
27	AUG	1600	18	0.18	0.17	0.01	2.	*	27	AUG	2330	48	0.00	0.00	0.00	2.
27	AUG	1615	19	0.01	0.00	0.00	5.	*	27	AUG	2345	49	0.00	0.00	0.00	2.
27	AUG	1630	20	0.20	0.16	0.04	12.	*	28	AUG	0000	50	0.00	0.00	0.00	2.
27	AUG	1645	21	0.13	0.09	0.04	24.	*	28	AUG	0015	51	0.00	0.00	0.00	2.
27	AUG	1700	22	0.06	0.04	0.02	40.	*	28	AUG	0030	52	0.00	0.00	0.00	2.
27	AUG	1715	23	0.01	0.01	0.00	48.	*	28	AUG	0045	53	0.00	0.00	0.00	2.
27	AUG	1730	24	0.00	0.00	0.00	46.	*	28	AUG	0100	54	0.00	0.00	0.00	1.
27	AUG	1745	25	0.00	0.00	0.00	35.	*	28	AUG	0115	55	0.00	0.00	0.00	1.
27	AUG	1800	26	0.00	0.00	0.00	24.	*	28	AUG	0130	56	0.00	0.00	0.00	1.
27	AUG	1815	27	0.00	0.00	0.00	15.	*	28	AUG	0145	57	0.00	0.00	0.00	1.
27	AUG	1830	28	0.00	0.00	0.00	12.	*	28	AUG	0200	58	0.00	0.00	0.00	1.
27	AUG	1845	29	0.00	0.00	0.00	11.	*	28	AUG	0215	59	0.00	0.00	0.00	1.
27	AUG	1900	30	0.00	0.00	0.00	10.	*	28	AUG	0230	60	0.00	0.00	0.00	1.

TOTAL RAINFALL = 1.10, TOTAL LOSS = 0.98, TOTAL EXCESS = 0.12

PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
(CFS)	(HR)		6-HR	24-HR	72-HR	14.75-HR
48.	5.50	(CFS)	15.	7.	7.	7.
		(INCHES)	0.157	0.179	0.179	0.179
		(AC-FT)	7.	8.	8.	8.

CUMULATIVE AREA = 0.87 SQ MI

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HYDROGRAPH AT STATION SB 1
PLAN 1. RATIO = 1.00

DA	MON	HRMN	ORD	FLOW	DA	MON	HRMN	ORD	FLOW	DA	MON	HRMN	ORD	FLOW	DA	MON	HRMN	ORD	FLOW
27	AUG	1145	1	1.	27	AUG	1530	16	0.	27	AUG	1915	31	9.	27	AUG	2300	46	3.
27	AUG	1200	2	1.	27	AUG	1545	17	0.	27	AUG	1930	32	8.	27	AUG	2315	47	3.
27	AUG	1215	3	1.	27	AUG	1600	18	2.	27	AUG	1945	33	8.	27	AUG	2330	48	2.
27	AUG	1230	4	1.	27	AUG	1615	19	5.	27	AUG	2000	34	7.	27	AUG	2345	49	2.
27	AUG	1245	5	1.	27	AUG	1630	20	12.	27	AUG	2015	35	7.	28	AUG	0000	50	2.
27	AUG	1300	6	1.	27	AUG	1645	21	24.	27	AUG	2030	36	6.	28	AUG	0015	51	2.
27	AUG	1315	7	1.	27	AUG	1700	22	40.	27	AUG	2045	37	6.	28	AUG	0030	52	2.
27	AUG	1330	8	1.	27	AUG	1715	23	48.	27	AUG	2100	38	5.	28	AUG	0045	53	2.
27	AUG	1345	9	1.	27	AUG	1730	24	46.	27	AUG	2115	39	5.	28	AUG	0100	54	1.
27	AUG	1400	10	1.	27	AUG	1745	25	35.	27	AUG	2130	40	4.	28	AUG	0115	55	1.
27	AUG	1415	11	1.	27	AUG	1800	26	24.	27	AUG	2145	41	4.	28	AUG	0130	56	1.
27	AUG	1430	12	1.	27	AUG	1815	27	15.	27	AUG	2200	42	4.	28	AUG	0145	57	1.
27	AUG	1445	13	0.	27	AUG	1830	28	12.	27	AUG	2215	43	3.	28	AUG	0200	58	1.
27	AUG	1500	14	0.	27	AUG	1845	29	11.	27	AUG	2230	44	3.	28	AUG	0215	59	1.
27	AUG	1515	15	0.	27	AUG	1900	30	10.	27	AUG	2245	45	3.	28	AUG	0230	60	1.

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	14.75-HR
48.	5.50	(CFS)	15.	7.	7.	7.
		(INCHES)	0.157	0.179	0.179	0.179
		(AC-FT)	7.	8.	8.	8.

CUMULATIVE AREA = 0.87 SQ MI

** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** **

Data, routing, and combining
for Subbasins 2 through 20
not shown

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND. AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

RATIOS APPLIED TO FLOWS

OPERATION	STATION	AREA	PLAN		RATIO 1 1.00
HYDROGRAPH AT	SB 1	0.87	1	FLOW	48.
				TIME	5.50
			2	FLOW	57.
				TIME	5.50
HYDROGRAPH AT	SB 2	0.42	1	FLOW	27.
				TIME	5.50
			2	FLOW	25.
				TIME	5.50

Subbasins 3 through 19
not shown

	SB 20	15.20	1	FLOW	1483.
				TIME	6.25
			2	FLOW	1705.
				TIME	6.25
HYDROGRAPH AT	SB 20	0.89	1	FLOW	219.
				TIME	5.50
			2	FLOW	277.
				TIME	5.50
2 COMBINED AT	SB 20	16.08	1	FLOW	1592.
				TIME	6.25
			2	FLOW	1841.
				TIME	6.00